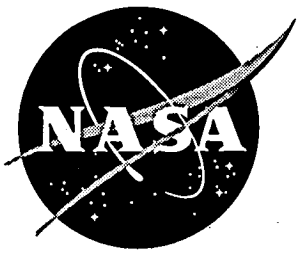
NASA Contractor Report 198248



NASA-CR-198248
19960014054

F-18 High Alpha Research Vehicle (HARV) Parameter Identification Flight Test Maneuvers for Optimal Input Design Validation and Lateral Control Effectiveness

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Contract NAS1-19000

December 1995

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Abstract

Flight test maneuvers are specified for the F-18 High Alpha Research Vehicle (HARV). The maneuvers were designed for open loop parameter identification purposes, specifically for optimal input design validation at 5 degrees angle of attack, identification of individual strake effectiveness at 40 and 50 degrees angle of attack, and study of lateral dynamics and lateral control effectiveness at 40 and 50 degrees angle of attack. Each maneuver is to be realized by applying square wave inputs to specific control effectors using the On-Board Excitation System (OBES). Maneuver descriptions and complete specifications of the time / amplitude points defining each input are included, along with plots of the input time histories.

Nomenclature

ANSER	Actuated Nose Strakes for Enhanced Rolling
h	altitude, feet
OBES	On-Board Excitation System
TV	thrust vectoring
t	time, seconds
V	airspeed, feet/second
α	angle of attack, degrees
δ_{a_r}	right aileron deflection in degrees, positive for trailing edge down
δ_{a_l}	left aileron deflection in degrees, positive for trailing edge down
δ_a	differential aileron deflection in degrees = $\left(\delta_{a_r} - \delta_{a_l}\right)/2$
δ_{r_r}	right rudder deflection in degrees, positive for trailing edge left
δ_{r_l}	left rudder deflection in degrees, positive for trailing edge left
δ_r	symmetric rudder deflection in degrees = $\left(\delta_{r_r} + \delta_{r_l}\right)/2$
δ_{s_r}	right stabilator deflection in degrees, positive for trailing edge down
δ_{s_l}	left stabilator deflection in degrees, positive for trailing edge down
δ_s	symmetric stabilator deflection in degrees = $\left(\delta_{s_r} + \delta_{s_l}\right)/2$
δ_{str_r}	right strake deflection in degrees, positive for outward deflection into the airstream
δ_{str_l}	left strake deflection in degrees, positive for outward deflection into the airstream
δ_{sstr}	symmetric strake deflection in degrees = $\left(\delta_{str_r} + \delta_{str_l}\right)/2$
δ_{dstr}	differential strake deflection in degrees = $\delta_{str_r} - \delta_{str_l}$
δ_{rtv}	roll thrust vectoring in degrees, positive for thrust vectoring to produce negative roll rate
δ_{ytv}	yaw thrust vectoring in degrees, positive for thrust vectoring to produce negative yaw rate

subscripts

o	nominal or trim value

I. Introduction

The F-18 High Alpha Research Vehicle (HARV) is a highly instrumented research aircraft used in the NASA High Alpha Technology Program[1]. Objectives for this program include investigating advanced flight testing techniques and determining the effectiveness of novel control effectors for maneuvering flight at high angles of attack.

In this work, the technique described in references [2] and [3] was used to design flight test maneuvers consisting of optimal open loop square wave inputs. These square wave inputs are to be applied directly to the relevant control effectors by the On-Board Excitation System (OBES)[4]. The optimal input design technique uses dynamic programming to compute globally optimal square wave inputs for model parameter estimation experiments, based on *a priori* dynamic models. Linear *a priori* dynamic models were obtained from an F-18 HARV nonlinear simulation[5] using central finite differences. The maneuvers were designed specifically to collect flight data with maximum information content for dynamic modeling purposes.

Specific objectives addressed by the maneuvers specified in this document are:

1. Study the efficacy of optimal square wave inputs implemented by the On-Board Excitation System (OBES) for aircraft parameter identification, including comparison with standard 3-2-1-1 input forms. Comparison of piloted optimal square wave inputs with piloted doublet inputs has been documented in reference [6].
2. Determine individual strake effectiveness at 40 and 50 degrees angle of attack for comparison with wind tunnel data and results from alternative flight test methods.
3. Study aircraft lateral dynamic response, differential strake effectiveness, and yaw / roll thrust vectoring effectiveness at 40 and 50 degrees angle of attack.
4. Update and verify existing aerodynamic models.

The purpose of this report is to document the specifications for the maneuvers designed to achieve the above objectives.

II. Maneuver Descriptions

There are thirteen (13) optimal square wave input maneuvers described in this report. The maneuvers can be divided into three groups:

1. Five (5) maneuvers for optimal input design validation using the OBES system.
2. Two (2) maneuvers for investigating individual strake effectiveness at 40 and 50 degrees angle of attack using the OBES system.
3. Six (6) maneuvers for studying lateral dynamic response and control effectiveness at 40 and 50 degrees angle of attack using the OBES system.

All maneuvers are to be flown using the Actuated Nose Strakes for Enhanced Rolling (ANSER) control law in thrust vectoring (TV) mode[7,8]. Control definitions and sign conventions are given above in the **Nomenclature** section. Detailed descriptions of the maneuvers in each group appear below, with numbering corresponding to that given above.

1. This group of five maneuvers is for studying the optimal input design technique. Initial flight condition is trim angle of attack 5 degrees and approximately 25,000 feet altitude, with the ANSER control law in TV mode. This initial flight condition applies for all five maneuvers.

The first two maneuvers involve deflection of the symmetric stabilator for studying optimal input design and for longitudinal model updates and verification. The first input is a standard 3-2-1-1 input, which will be compared to the second input, an optimal square wave, in terms of efficacy for longitudinal dynamic response flight testing. It is therefore important that these two maneuvers be run in sequence on the same flight to minimize extraneous influences on the comparison. Input specifications for the symmetric stabilator 3-2-1-1 input are given in Table 1, and the optimal symmetric stabilator specifications are given in Table 2. Figures 1 and 2 show time histories for the 3-2-1-1 and optimal inputs, respectively. Both inputs included a rate limit of 40 degrees/second for the symmetric stabilator.

The next three maneuvers involve deflection of the rudder and aileron for studying optimal multiple input design and for lateral model updates and verification. The first input is a standard 3-2-1-1 input, which will be compared to the next two inputs, a sequential optimal square wave and a simultaneous optimal square wave, in terms of efficacy for lateral dynamic response flight testing. It is therefore important that these three maneuvers be run in sequence on the same flight to minimize extraneous influences on the comparison. Input specifications for the rudder / aileron 3-2-1-1 input are given in Table 3, specifications for the sequential rudder / aileron optimal input are given in Table 4, and the specifications for the simultaneous rudder / aileron optimal input are given in Table 5. Figures 3, 4, and 5 show time histories for the 3-2-1-1, sequential optimal, and

simultaneous optimal inputs, respectively. All inputs included a rate limits of 75 degrees/second for rudder and 100 degrees/second for aileron.

Each of the five maneuvers in this group is to be flown two (2) times, for a total of ten (10) runs. Each run should be preceded by at least two seconds of steady trimmed flight, and followed by at least two seconds of free response before the pilot takes action to control the aircraft. The duration of each maneuver is 20 seconds. Estimated flight time for this set of maneuvers (including repeats) is approximately 15 minutes.

2. This group of two maneuvers is for studying the effectiveness of individual strake deflections at high angles of attack, independent of the scheduled symmetric strake deployment associated with the ANSER control law.

For the first maneuver, initial flight condition is trim angle of attack 40 degrees and approximately 25,000 feet altitude, with the ANSER control law in TV mode. This maneuver involves independent deflection of the left and right strakes for studying individual strake effectiveness. Input specifications for the left / right strake optimal square wave input are given in Table 6. Figure 6 shows time histories for the optimal strake inputs. The inputs included a rate limit of 100 degrees/second for both left and right strakes.

For the second maneuver, initial flight condition is trim angle of attack 50 degrees and approximately 25,000 feet altitude, with the ANSER control law in TV mode. This maneuver involves independent deflection of the left and right strakes for studying individual strake effectiveness. Input specifications for the left / right strake optimal square wave input are given in Table 7. Figure 7 shows time histories for the optimal strake inputs. The inputs included a rate limit of 100 degrees/second for both left and right strakes

Both maneuvers in this group are to be flown two (2) times, for a total of four (4) runs. Each run should be preceded by at least two seconds of steady trimmed flight, and followed by at least two seconds of free response before the pilot takes action to control the aircraft. The duration of each maneuver is 24 seconds. Estimated flight time for this set of maneuvers (including repeats) is approximately 10 minutes.

3. This group of six maneuvers is for studying lateral dynamics and control effectiveness at high angle of attack. There are three different types of maneuver in this group. A maneuver of each type was designed for two initial flight conditions:

a.) Trim angle of attack 40 degrees and approximately 25,000 feet altitude, with the ANSER control law in TV mode.

b.) Trim angle of attack 50 degrees and approximately 25,000 feet altitude, with the ANSER control law in TV mode.

A description of each maneuver type and the corresponding input specifications for the two flight conditions listed above are given next.

The first maneuver type involves simultaneous deflection of the rudder and aileron for studying lateral dynamic response and for model updates and verification. Input specifications for the rudder / aileron optimal square wave inputs are given in Table 8 for 40 degrees angle of attack, and in Table 11 for 50 degrees angle of attack. Figures 8 and 11 show time histories of the optimal inputs for 40 degrees angle of attack and 50 degrees angle of attack, respectively. All inputs included rate limits of 82 degrees/second for rudder and 100 degrees/second for aileron.

The second maneuver type involves simultaneous deflection of the yaw thrust vectoring and differential strake for studying yaw thrust vectoring effectiveness and differential strake effectiveness, and for model updates and verification. A symmetric strake deflection must be applied slowly before the start of this maneuver. The symmetric strake deflection δ_{sstr} is computed as:

$$\delta_{sstr} = (\alpha_o - 30) \text{ degrees} \qquad \text{for } \alpha_o > 30 \text{ degrees}$$

or,

$$\delta_{sstr} = 10 \text{ degrees for } \alpha_o = 40 \text{ degrees}$$

$$\delta_{sstr} = 20 \text{ degrees for } \alpha_o = 50 \text{ degrees}$$

Input specifications for the yaw thrust vectoring / differential strake optimal square wave inputs are given in Table 9 for 40 degrees angle of attack, and in Table 12 for 50 degrees angle of attack. Individual strake deflections are non-negative and are computed by combining the symmetric strake deflection δ_{sstr} with the differential strake deflections δ_{dstr} from Tables 9 and 12, using the following logic:

if (abs(δ_{dstr}) $\leq$ 2.0*(δ_{sstr})) then

$$\delta_{str_l} = \delta_{sstr} - 0.5*(\delta_{dstr})$$

$$\delta_{str_r} = \delta_{sstr} + 0.5*(\delta_{dstr})$$

else

if ($\delta_{dstr} > 0.0$) then

$$\delta_{str_l} = 0.0$$

$$\delta_{str_r} = \delta_{dstr}$$

else

$$\delta_{str_l} = -\delta_{dstr}$$

$$\delta_{str_r} = 0.0$$

end if

end if

Figures 9 and 12 show time histories of the optimal inputs for 40 degrees angle of attack and 50 degrees angle of attack, respectively. All inputs included rate limits of 100 degrees/second for yaw thrust vectoring and 180 degrees/second for differential strake.

The third maneuver type involves sequential deflection of the rudder, aileron, yaw thrust vectoring, differential strake, and roll thrust vectoring for studying control effectiveness and optimal input design, and for model updates and verification. A symmetric strake deflection must be applied slowly before the start of this maneuver. The symmetric strake deflection δ_{sstr} is computed as:

$$\delta_{sstr} = (\alpha_o - 30) \text{ degrees} \qquad \text{for } \alpha_o > 30 \text{ degrees}$$

or,

$$\delta_{sstr} = 10 \text{ degrees for } \alpha_o = 40 \text{ degrees}$$

$$\delta_{sstr} = 20 \text{ degrees for } \alpha_o = 50 \text{ degrees}$$

Input specifications for the rudder / aileron / yaw thrust vectoring / differential strake / roll thrust vectoring optimal square wave inputs are given in Table 10 for 40 degrees angle of attack, and in Table 13 for 50 degrees angle of attack. Individual strake deflections are computed exactly as described above for the second maneuver type in this set. Figures 10 and 13 show time histories of the optimal inputs for 40 degrees angle of attack and 50 degrees angle of attack, respectively. All inputs included rate limits of 82 degrees/second for rudder, 100 degrees/second for aileron, 100 degrees/second for yaw thrust vectoring, 180 degrees/second for differential strake, and 100 degrees/second for roll thrust vectoring.

Each of the six maneuvers in this group is to be flown two (2) times, for a total of twelve (12) runs. Each run should be preceded by at least two seconds of steady trimmed flight, and followed by at least two seconds of free response before the pilot takes action to control the aircraft. The duration of the rudder / aileron maneuvers and the yaw thrust vectoring / differential strake maneuvers is 15 seconds. The duration of the sequential rudder / aileron / yaw thrust vectoring / differential strake / roll thrust vectoring maneuvers is 21 seconds. Estimated flight time for this set of maneuvers (including repeats) is approximately 20 minutes.

III. Acknowledgments

This research was conducted at the NASA Langley Research Center under NASA contract NAS1-19000.

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V. Input Specification Tables

5 α 3-2-1-1 LONGITUDINAL STABILATOR MANEUVER

Initial Conditions

$\alpha_o = 5°$

$V_o = 370$ knots

$h_o = 25{,}000$ feet

| OBES δ_s |$_{max} = 3.0$ degrees

Table 1

(Figure 1)

OBES stabilator

Time (seconds)	OBES δ_s (degrees)
0	0
0.025	3
3.000	3
3.050	-3
5.000	-3
5.050	3
6.000	3
6.050	-3
7.000	-3
7.025	0
12.000	0
12.025	-3
15.000	-3
15.050	3
17.000	3
17.050	-3
18.000	-3
18.050	3
19.000	3
19.025	0
24.000	0

5 α OPTIMAL LONGITUDINAL STABILATOR MANEUVER

Initial Conditions

$\alpha_o = 5°$

$V_o = 370$ knots

$h_o = 25{,}000$ feet

| OBES δ_s |$_{max} = 4.0$ degrees

Table 2

(Figure 2)

OBES stabilator

Time (seconds)	OBES δ_s (degrees)
0	0
0.100	4
2.500	4
2.700	-4
3.000	-4
3.200	4
3.500	4
3.700	-4
6.000	-4
6.200	4
6.500	4
6.700	-4
7.000	-4
7.200	4
9.750	4
9.950	-4
10.250	-4
10.450	4
10.750	4
10.950	-4
13.250	-4
13.450	4

(cont.)

Table 2 (cont.)
(Figure 2)

OBES stabilator

Time (seconds)	OBES δ_s (degrees)
13.750	4
13.950	-4
14.250	-4
14.450	4
17.000	4
17.200	-4
17.500	-4
17.700	4
18.000	4
18.200	-4
20.000	-4
20.200	4
20.500	4
20.700	-4
21.000	-4
21.200	4
22.250	4
22.450	-4
22.750	-4
22.950	4
23.250	4
23.450	-4
23.750	-4
23.850	0
24.000	0

5 α 3-2-1-1 LATERAL RUDDER / AILERON MANEUVER

Initial Conditions

$\alpha_o = 5°$

$V_o = 370$ knots

$h_o = 25{,}000$ feet

| OBES δ_r |$_{max} = 4.0$ degrees

| OBES δ_a |$_{max} = 2.5$ degrees

Table 3

(Figure 3)

OBES rudder

Time (seconds)	OBES δ_r (degrees)
0	0
0.050	4
2.675	4
2.775	-4
4.475	-4
4.575	4
5.375	4
5.475	-4
6.275	-4
6.325	0
20.000	0

OBES aileron

Time (seconds)	OBES δ_a (degrees)
0	0
10.000	0
10.025	-2.5
12.675	-2.5
12.725	2.5
14.475	2.5
14.525	-2.5
15.375	-2.5
15.425	2.5
16.275	2.5
16.300	0
20.000	0

5 α SEQUENTIAL OPTIMAL LATERAL RUDDER / AILERON MANEUVER

Initial Conditions

$\alpha_o = 5°$

$V_o = 370$ knots

$h_o = 25{,}000$ feet

| OBES δ_r |$_{max} = 4.0$ degrees

| OBES δ_a |$_{max} = 2.5$ degrees

Table 4

(Figure 4)

OBES rudder

Time (seconds)	OBES δ_r (degrees)
0	0
0.075	4
0.900	4
0.975	0
1.125	0
1.200	4
1.575	4
1.650	0
2.025	0
2.100	4
2.475	4
2.550	0
2.700	0
2.775	4
3.600	4
3.675	0
3.825	0
3.900	4
4.050	4
4.175	-4
6.075	-4

(cont.)

OBES aileron

Time (seconds)	OBES δ_a (degrees)
0	0
10.125	0
10.150	-2.5
11.925	-2.5
11.975	2.5
13.050	2.5
13.100	-2.5
14.400	-2.5
14.450	2.5
18.000	2.5
18.025	0
18.450	0
18.475	-2.5
19.800	-2.5
19.825	0
20.000	0

Table 4 (cont.)

(Figure 4)

OBES rudder

Time (seconds)	OBES δ_r (degrees)
6.200	4
7.200	4
7.325	-4
7.425	-4
7.500	0
7.650	0
7.725	-4
7.875	-4
7.950	0
8.100	0
8.175	4
8.775	4
8.900	-4
10.125	-4
10.200	0
20.000	0

5 α OPTIMAL LATERAL RUDDER / AILERON MANEUVER

Initial Conditions

$\alpha_o = 5°$

$V_o = 370$ knots

$h_o = 25{,}000$ feet

| OBES δ_r |$_{max} = 4.0$ degrees

| OBES δ_a |$_{max} = 2.5$ degrees

Table 5

(Figure 5)

OBES rudder

Time (seconds)	OBES δ_r (degrees)
0	0
0.075	-4
0.225	-4
0.300	0
0.450	0
0.525	-4
1.350	-4
1.475	4
1.800	4
1.875	0
2.025	0
2.100	4
2.250	4
2.375	-4
2.700	-4
2.825	4
2.925	4
3.050	-4
4.500	-4
4.625	4
4.725	4

OBES aileron

Time (seconds)	OBES δ_a (degrees)
0	0
0.025	2.5
1.125	2.5
1.175	-2.5
1.350	-2.5
1.400	2.5
1.800	2.5
1.850	-2.5
2.475	-2.5
2.525	2.5
3.150	2.5
3.200	-2.5
5.175	-2.5
5.200	0
5.400	0
5.425	2.5
9.225	2.5
9.250	0
9.450	0
9.475	-2.5
11.250	-2.5

(cont.)

Table 5 (cont.)

(Figure 5)

OBES rudder

Time (seconds)	OBES δ_r (degrees)
4.800	0
4.950	0
5.025	4
6.075	4
6.200	-4
6.300	-4
6.375	0
6.525	0
6.600	-4
6.975	-4
7.050	0
7.200	0
7.275	4
7.875	4
8.000	-4
8.775	-4
8.850	0
9.000	0
9.075	4
9.900	4
10.025	-4
11.475	-4
11.550	0
11.700	0
11.775	4
12.150	4
12.225	0
12.375	0
12.450	4
12.600	4
12.725	-4
12.825	-4

(cont.)

OBES aileron

Time (seconds)	OBES δ_a (degrees)
11.300	2.5
11.925	2.5
11.975	-2.5
13.725	-2.5
13.775	2.5
14.625	2.5
14.650	0
14.850	0
14.875	-2.5
15.750	-2.5
15.800	2.5
17.775	2.5
17.825	-2.5
18.675	-2.5
18.725	2.5
19.800	2.5
19.825	0
20.000	0

Table 5 (cont.)
(Figure 5)

OBES rudder

Time (seconds)	OBES δ_r (degrees)
12.950	4
13.050	4
13.175	-4
14.400	-4
14.525	4
14.850	4
14.925	0
15.075	0
15.150	4
16.200	4
16.325	-4
16.650	-4
16.775	4
16.875	4
17.000	-4
17.325	-4
17.400	0
17.775	0
17.850	4
18.000	4
18.125	-4
18.225	-4
18.350	4
19.350	4
19.475	-4
19.575	-4
19.700	4
19.800	4
19.875	0
20.000	0

40 α OPTIMAL STRAKE MANEUVER

Initial Conditions

$\alpha_o = 40°$

$V_o = 155$ knots

$h_o = 25{,}000$ feet

$|\text{OBES } \delta_{str_l}|_{max} = 30.0$ degrees $\qquad$ $|\text{OBES } \delta_{str_r}|_{max} = 30.0$ degrees

Table 6

(Figure 6)

OBES left strake

Time (seconds)	OBES δ_{str_l} (degrees)
0	0
0.900	0
1.200	30
1.500	0
3.000	0
3.300	30
3.600	30
3.900	0
5.700	0
6.000	30
6.300	0
7.800	0
8.100	30
8.400	0
9.000	0
9.300	30
9.900	30
10.200	0
11.700	0
12.000	30
12.300	30
12.600	0
13.800	0

OBES right strake

Time (seconds)	OBES δ_{str_r} (degrees)
0	0
0.300	30
0.600	30
0.900	0
4.800	0
5.100	30
5.400	30
5.700	0
6.600	0
6.900	30
7.500	30
7.800	0
10.500	0
10.800	30
11.400	30
11.700	0
12.900	0
13.200	30
13.500	30
13.800	0
15.000	0
15.300	30
16.200	30

(cont.)

Table 6 (cont.)

(Figure 6)

OBES left strake

Time (seconds)	OBES δ_{str_l} (degrees)
14.100	30
14.400	30
14.700	0
16.500	0
16.800	30
17.700	30
18.000	0
19.200	0
19.500	30
19.800	30
20.100	0
21.300	0
21.600	30
21.900	0
22.200	0
22.500	30
22.800	30
23.100	0
24.000	0

OBES right strake

Time (seconds)	OBES δ_{str_r} (degrees)
16.500	0
18.300	0
18.600	30
18.900	30
19.200	0
20.400	0
20.700	30
21.000	30
21.300	0
24.000	0

50 α OPTIMAL STRAKE MANEUVER

Initial Conditions

$\alpha_o = 50°$

$V_o = 155$ knots

$h_o = 25{,}000$ feet

$|\text{OBES } \delta_{str_l}|_{max} = 40.0$ degrees $\qquad$ $|\text{OBES } \delta_{str_r}|_{max} = 40.0$ degrees

Table 7

(Figure 7)

OBES left strake

Time (seconds)	OBES δ_{str_l} (degrees)
0	0
1.200	0
1.600	40
2.000	0
4.000	0
4.400	40
5.200	40
5.600	0
7.200	0
7.600	40
8.400	40
8.800	0
10.400	0
10.800	40
11.200	40
11.600	0
14.400	0
14.800	40
15.200	0
17.200	0
17.600	40
18.000	0
18.400	0

OBES right strake

Time (seconds)	OBES δ_{str_r} (degrees)
0	0
0.400	40
0.800	40
1.200	0
2.800	0
3.200	40
3.600	40
4.000	0
6.000	0
6.400	40
6.800	40
7.200	0
9.200	0
9.600	40
10.000	40
10.400	0
12.800	0
13.200	40
14.000	40
14.400	0
16.000	0
16.400	40
16.800	40

(cont.)

Table 7 (cont.)

(Figure 7)

OBES left strake

Time (seconds)	OBES δ_{str_l} (degrees)
18.800	40
19.200	40
19.600	0
22.800	0
23.200	40
23.600	40
24.000	0

OBES right strake

Time (seconds)	OBES δ_{str_r} (degrees)
17.200	0
24.000	0

40 α OPTIMAL LATERAL RUDDER / AILERON MANEUVER

Initial Conditions

$\alpha_o = 40°$

$V_o = 155$ knots

$h_o = 25{,}000$ feet

| OBES δ_r |$_{max} = 18.0$ degrees

| OBES δ_a |$_{max} = 20.0$ degrees

Table 8

(Figure 8)

OBES rudder

Time (seconds)	OBES δ_r (degrees)
0	0
0.2000	18
0.5000	18
0.7000	0
1.0000	0
1.2000	-18
1.5000	-18
1.7000	0
2.0000	0
2.2000	-18
2.5000	-18
2.7000	0
3.0000	0
3.2000	18
3.5000	18
3.7000	0
4.0000	0
4.2000	-18
4.5000	-18
4.8750	18
5.0000	18

OBES aileron

Time (seconds)	OBES δ_a (degrees)
0	0
0.2500	20
0.5000	20
0.7500	0
1.0000	0
1.2500	-20
3.5000	-20
4.0000	20
4.5000	20
5.0000	-20
6.5000	-20
7.0000	20
8.5000	20
8.7500	0
9.0000	0
9.2500	20
10.0000	20
10.2500	0
10.5000	0
10.7500	20
12.5000	20

(cont.)

Table 8 (cont.)

(Figure 8)

OBES rudder

Time (seconds)	OBES δ_r (degrees)
5.3750	-18
5.5000	-18
5.8750	18
6.5000	18
6.7000	0
7.0000	0
7.2000	-18
8.0000	-18
8.2000	0
8.5000	0
8.7000	18
9.0000	18
9.2000	0
9.5000	0
9.7000	18
10.5000	18
10.8750	-18
11.5000	-18
11.7000	0
13.0000	0
13.2000	18
13.5000	18
13.8750	-18
14.5000	-18
14.7000	0
15.0000	0

OBES aileron

Time (seconds)	OBES δ_a (degrees)
12.7500	0
13.0000	0
13.2500	-20
14.0000	-20
14.5000	20
14.5500	20
14.7500	0
15.0000	0

40 α OPTIMAL LATERAL YAW TV / DIFFERENTIAL STRAKE MANEUVER

Initial Conditions

$\alpha_o = 40°$

$V_o = 155$ knots

$h_o = 25{,}000$ feet

| OBES δ_{ytv} |$_{max} = 6.0$ degrees

| OBES δ_{dstr} |$_{max} = 20.0$ degrees

Table 9

(Figure 9)

OBES yaw thrust vectoring

Time (seconds)	OBES δ_{ytv} (degrees)
0	0
0.0750	6
0.4500	6
0.5750	-6
0.7500	-6
0.8750	6
1.0500	6
1.1750	-6
2.2500	-6
2.3750	6
2.8500	6
2.9250	0
3.1500	0
3.2250	6
4.2000	6
4.3250	-6
5.2500	-6
5.3250	0
5.7000	0
5.7750	6
6.4500	6
6.5250	0
6.7500	0

OBES differential strake

Time (seconds)	OBES δ_{dstr} (degrees)
0	0
0.1250	-20
0.3000	-20
0.4250	0
0.9000	0
1.0250	20
1.2000	20
1.4250	-20
1.8000	-20
2.0250	20
2.7000	20
2.9250	-20
3.0000	-20
3.2250	20
3.4500	20
3.5750	0
3.7500	0
3.8750	20
4.5000	20
4.7250	-20
5.8500	-20
5.9750	0
6.3000	0

(cont.)

Table 9 (cont.)

(Figure 9)

OBES yaw thrust vectoring

Time (seconds)	OBES δ_{ytv} (degrees)
6.8250	6
7.0500	6
7.1750	-6
8.2500	-6
8.3250	0
8.5500	0
8.6250	6
9.1500	6
9.2250	0
9.9000	0
9.9750	-6
10.8000	-6
10.8750	0
11.1000	0
11.1750	-6
11.4000	-6
11.5250	6
11.7000	6
11.8250	-6
12.0000	-6
12.1250	6
13.0500	6
13.1250	0
13.3500	0
13.4250	6
14.7000	6
14.7750	0
15.0000	0

OBES differential strake

Time (seconds)	OBES δ_{dstr} (degrees)
6.4250	-20
6.6000	-20
6.8250	20
8.1000	20
8.2250	0
8.4000	0
8.5250	-20
9.6000	-20
9.7250	0
9.9000	0
10.0250	-20
10.3500	-20
10.5750	20
10.8000	20
10.9250	0
11.1000	0
11.2250	-20
11.5500	-20
11.7750	20
12.0000	20
12.1250	0
12.6000	0
12.7250	20
13.6500	20
13.7750	0
13.9500	0
14.0750	20
14.2500	20
14.4750	-20
14.7000	-20
14.8250	0
15.0000	0

40 α OPTIMAL LATERAL SEQUENTIAL MANEUVER

Initial Conditions

$\alpha_o = 40°$

V_o = 155 knots

h_o = 25,000 feet

OBES δ_r |$_{max}$ = 19.0 degrees		OBES δ_a |$_{max}$ = 18.0 degrees
OBES δ_{ytv} |$_{max}$ = 6.0 degrees		OBES δ_{dstr} |$_{max}$ = 20.0 degrees

OBES δ_{rtv} |$_{max}$ = 10.0 degrees

Table 10

(Figure 10)

OBES rudder		OBES aileron		OBES yaw TV		OBES diff. strake		OBES roll TV	
Time (sec)	OBES δ_r (deg)	Time (sec)	OBES δ_a (deg)	Time (sec)	OBES δ_{ytv} (deg)	Time (sec)	OBES δ_{dstr} (deg)	Time (sec)	OBES δ_{rtv} (deg)
0	0	0	0	0	0	0	0	0	0
0.250	19	4.000	0	8.000	0	12.000	0	16.000	0
0.500	19	4.200	18	8.075	6	12.125	20	16.100	-10
0.750	0	4.500	18	9.500	6	12.500	20	17.000	-10
1.000	0	4.875	-18	9.625	-6	12.725	-20	17.100	0
1.250	19	5.000	-18	11.000	-6	13.500	-20	17.500	0
1.500	19	5.375	18	11.075	0	13.625	0	17.600	10
1.975	-19	5.500	18	11.500	0	14.000	0	18.000	10
2.000	-19	5.875	-18	11.575	6	14.125	20	18.100	0
2.475	19	6.000	-18	12.000	6	15.000	20	18.500	0
2.500	19	6.200	0	12.075	0	15.225	-20	18.600	10
2.975	-19	6.500	0	21.000	0	15.500	-20	19.500	10
3.000	-19	6.700	-18			15.625	0	19.700	-10
3.250	0	7.000	-18			21.000	0	20.000	-10
3.500	0	7.375	18					20.100	0
3.750	19	8.000	18					21.000	0
4.000	19	8.200	0						
4.250	0	21.000	0						
21.000	0								

50 α OPTIMAL LATERAL RUDDER / AILERON MANEUVER

Initial Conditions

$\alpha_o = 50°$

$V_o = 155$ knots

$h_o = 25{,}000$ feet

| OBES δ_r |$_{max}$ = 20.0 degrees

| OBES δ_a |$_{max}$ = 20.0 degrees

Table 11

(Figure 11)

OBES rudder

Time (seconds)	OBES δ_r (degrees)
0	0
0.250	-20
0.500	-20
1.000	20
2.000	20
2.250	0
3.000	0
3.250	-20
4.000	-20
4.500	20
5.000	20
5.250	0
5.500	0
5.750	-20
6.000	-20
6.250	0
7.000	0
7.250	-20
7.500	-20
7.750	0
8.500	0

OBES aileron

Time (seconds)	OBES δ_a (degrees)
0	0
0.200	-20
0.500	-20
0.700	0
1.000	0
1.200	20
1.500	20
1.700	0
2.000	0
2.200	-20
2.500	-20
2.700	0
3.000	0
3.200	20
4.000	20
4.200	0
4.500	0
4.700	-20
5.000	-20
5.400	20
6.500	20

(cont.)

Table 11 (cont.)

(Figure 11)

OBES rudder

Time (seconds)	OBES δ_r (degrees)
8.750	20
9.500	20
9.750	0
10.000	0
10.250	20
10.500	20
10.750	0
13.000	0
13.250	-20
13.500	-20
13.750	0
15.000	0

OBES aileron

Time (seconds)	OBES δ_a (degrees)
6.900	-20
7.500	-20
7.700	0
8.000	0
8.200	20
8.500	20
8.900	-20
9.000	-20
9.200	0
9.500	0
9.700	-20
10.500	-20
10.700	0
11.000	0
11.200	-20
11.500	-20
11.900	20
12.000	20
12.200	0
12.500	0
12.700	-20
13.000	-20
13.200	0
13.500	0
13.700	-20
14.000	-20
14.400	20
14.500	20
14.700	0
15.000	0

50 α OPTIMAL LATERAL YAW TV / DIFFERENTIAL STRAKE MANEUVER

Initial Conditions

$\alpha_o = 50°$

$V_o = 155$ knots

$h_o = 25{,}000$ feet

| OBES δ_{ytv} |$_{max} = 5.0$ degrees

| OBES δ_{dstr} |$_{max} = 15.0$ degrees

Table 12

(Figure 12)

OBES yaw thrust vectoring

Time (seconds)	OBES δ_{ytv} (degrees)
0	0
0.050	5
0.800	5
0.850	0
1.000	0
1.050	-5
1.200	-5
1.250	0
1.400	0
1.450	-5
1.800	-5
1.900	5
2.000	5
2.050	0
2.400	0
2.450	5
2.600	5
2.700	-5
2.800	-5
2.850	0
3.000	0
3.050	-5
3.600	-5
3.700	5

OBES differential strake

Time (seconds)	OBES δ_{dstr} (degrees)
0	0
0.100	15
0.800	15
0.975	-15
2.000	-15
2.175	15
2.200	15
2.375	-15
2.600	-15
2.775	15
3.400	15
3.575	-15
4.800	-15
4.975	15
5.600	15
5.775	-15
5.800	-15
5.900	0
6.000	0
6.100	-15
6.200	-15
6.300	0
6.400	0
6.500	-15

(cont.)

Table 12 (cont.)

(Figure 12)

OBES yaw thrust vectoring

Time (seconds)	OBES δ_{ytv} (degrees)
4.200	5
4.250	0
4.400	0
4.450	-5
6.000	-5
6.100	5
8.200	5
8.300	-5
8.800	-5
8.850	0
9.000	0
9.050	-5
9.200	-5
9.300	5
10.800	5
10.900	-5
11.200	-5
11.250	0
11.600	0
11.650	-5
11.800	-5
11.850	0
12.000	0
12.050	-5
12.200	-5
12.300	5
12.400	5
12.500	-5
12.600	-5
12.700	5
14.800	5
14.850	0
15.000	0

OBES differential strake

Time (seconds)	OBES δ_{dstr} (degrees)
6.800	-15
6.975	15
7.200	15
7.375	-15
9.200	-15
9.300	0
9.400	0
9.500	-15
10.200	-15
10.375	15
10.800	15
10.900	0
11.200	0
11.300	15
12.000	15
12.175	-15
13.600	-15
13.775	15
14.800	15
14.900	0
15.000	0

50 α OPTIMAL LATERAL SEQUENTIAL MANEUVER

Initial Conditions

$\alpha_o = 50°$

$V_o = 155$ knots

$h_o = 25{,}000$ feet

OBES δ_r |$_{max}$ = 19.0 degrees		OBES δ_a |$_{max}$ = 20.0 degrees
OBES δ_{ytv} |$_{max}$ = 5.0 degrees		OBES δ_{dstr} |$_{max}$ = 20.0 degrees

OBES δ_{rtv} |$_{max}$ = 10.0 degrees

Table 13

(Figure 13)

OBES rudder		OBES aileron		OBES yaw TV		OBES diff. strake		OBES roll TV	
Time (sec)	OBES δ_r (deg)	Time (sec)	OBES δ_a (deg)	Time (sec)	OBES δ_{ytv} (deg)	Time (sec)	OBES δ_{dstr} (deg)	Time (sec)	OBES δ_{rtv} (deg)
0	0	0	0	0	0	0	0	0	0
0.250	-19	4.000	0	8.000	0	12.000	0	16.000	0
2.500	-19	4.200	20	8.050	5	12.125	-20	16.100	10
2.975	19	4.500	20	9.500	5	14.000	-20	17.000	10
3.000	19	4.900	-20	9.600	-5	14.225	20	17.200	-10
3.250	0	5.500	-20	10.500	-5	16.000	20	18.000	-10
3.500	0	5.900	20	10.600	5	16.125	0	18.100	0
3.750	-19	6.500	20	11.000	5	21.000	0	18.500	0
4.000	-19	6.900	-20	11.050	0			18.600	10
4.250	0	7.500	-20	11.500	0			20.000	10
21.000	0	7.900	20	11.550	5			20.100	0
		8.000	20	12.000	5			21.000	0
		8.200	0	12.050	0				
		21.000	0	21.000	0				

VI. Control Time Histories

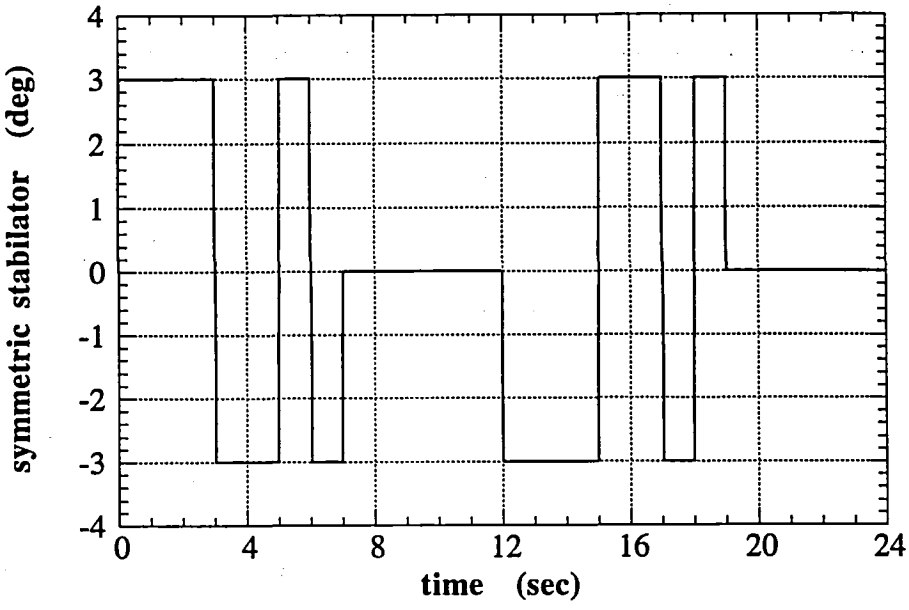


Figure 1 F-18 HARV 3-2-1-1 Longitudinal Stabilator Input, $\alpha = 5$ degrees

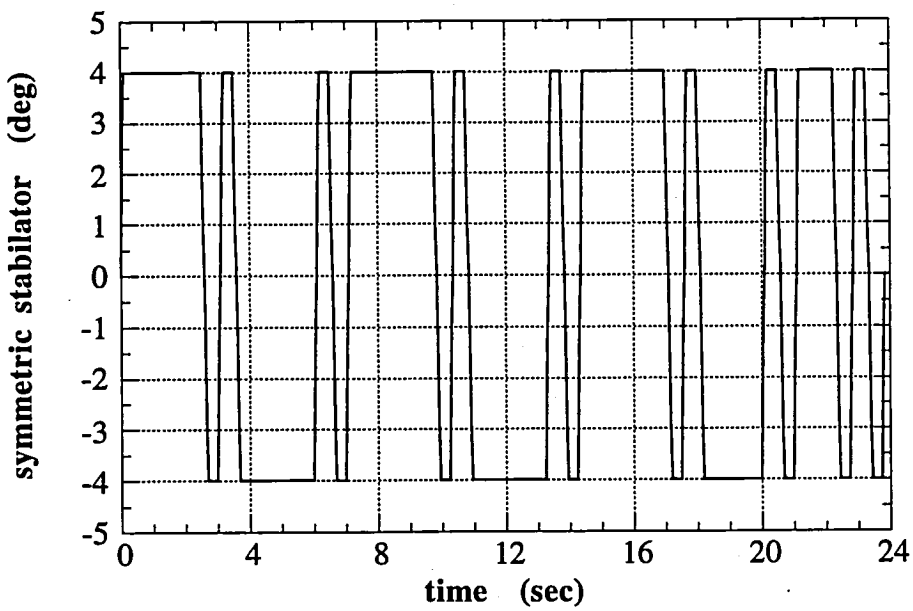
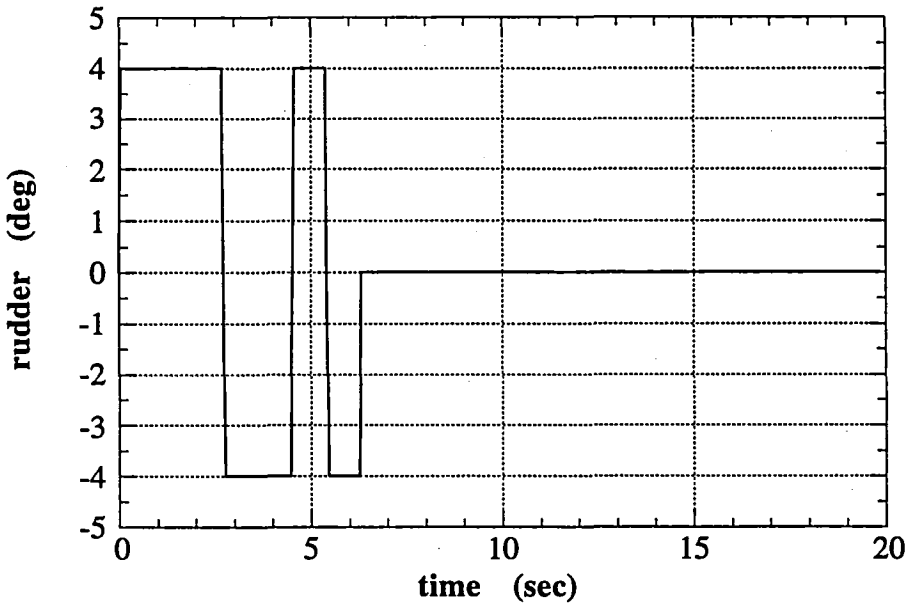


Figure 2 F-18 HARV Optimal Longitudinal Stabilator Input, $\alpha = 5$ degrees



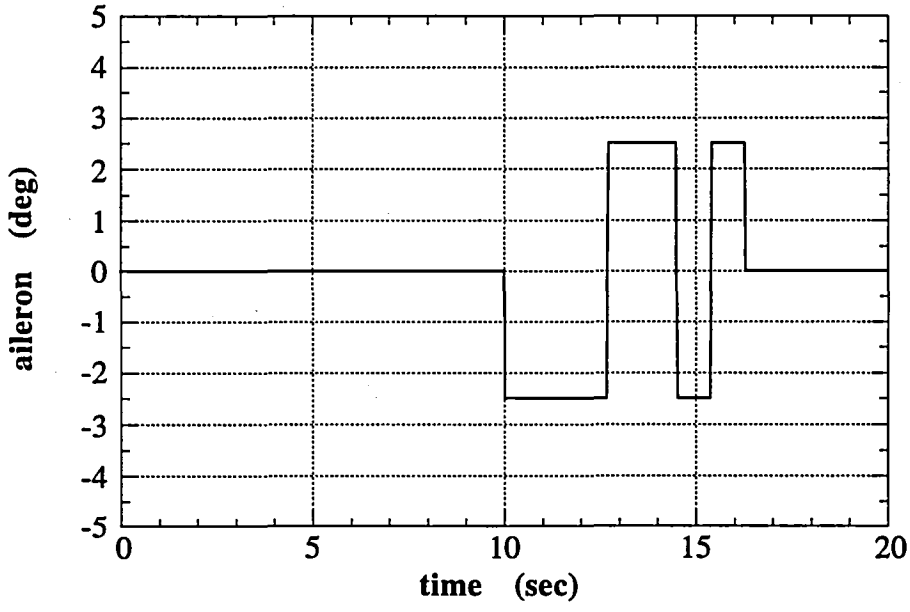


Figure 3 F-18 HARV 3-2-1-1 Lateral Rudder/Aileron Inputs, $\alpha = 5$ degrees

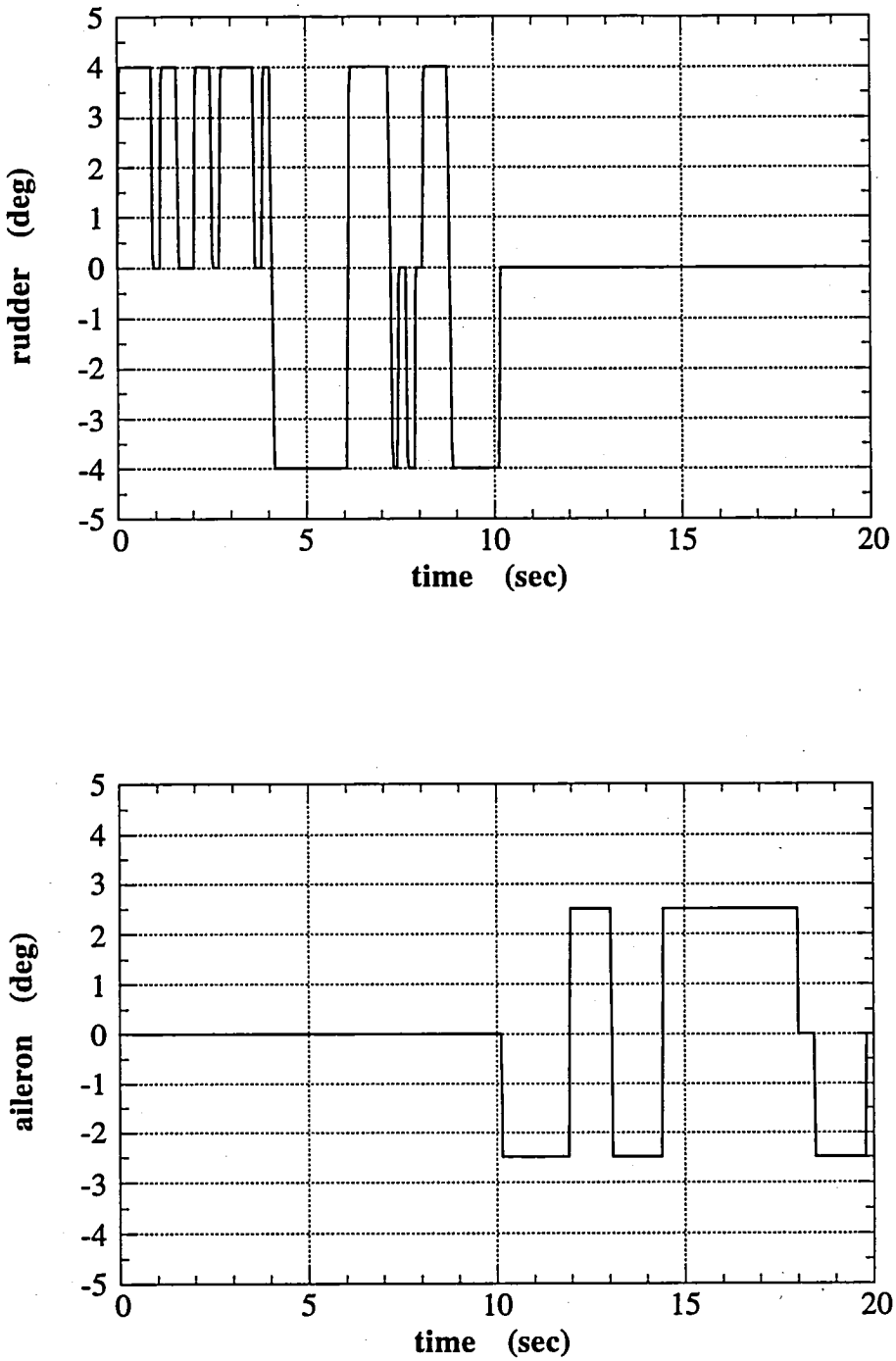


Figure 4 F-18 HARV Sequential Optimal Lateral Rudder/Aileron Inputs, $\alpha = 5$ degrees

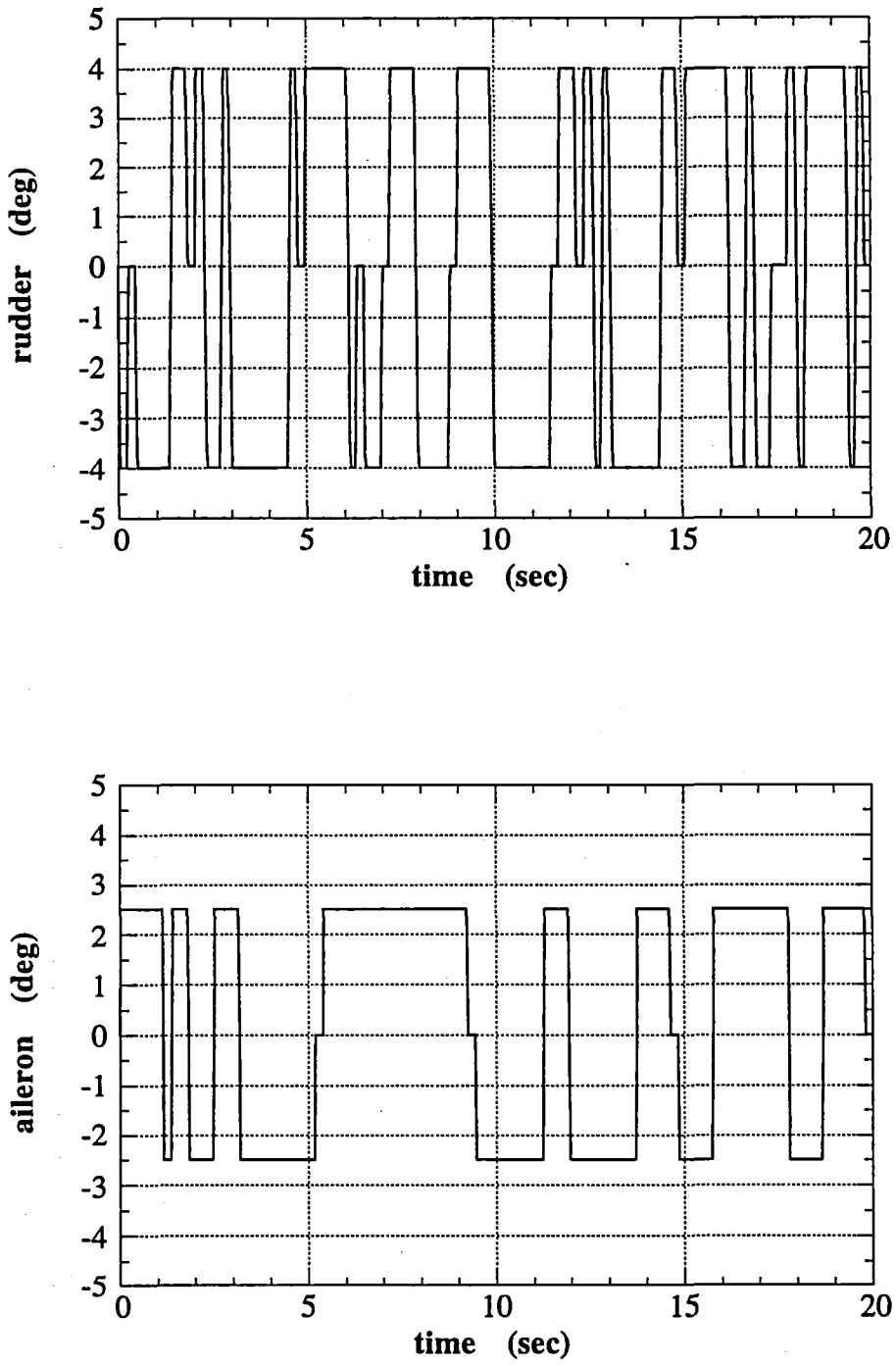


Figure 5 F-18 HARV Optimal Lateral Rudder/Aileron Inputs, $\alpha = 5$ degrees

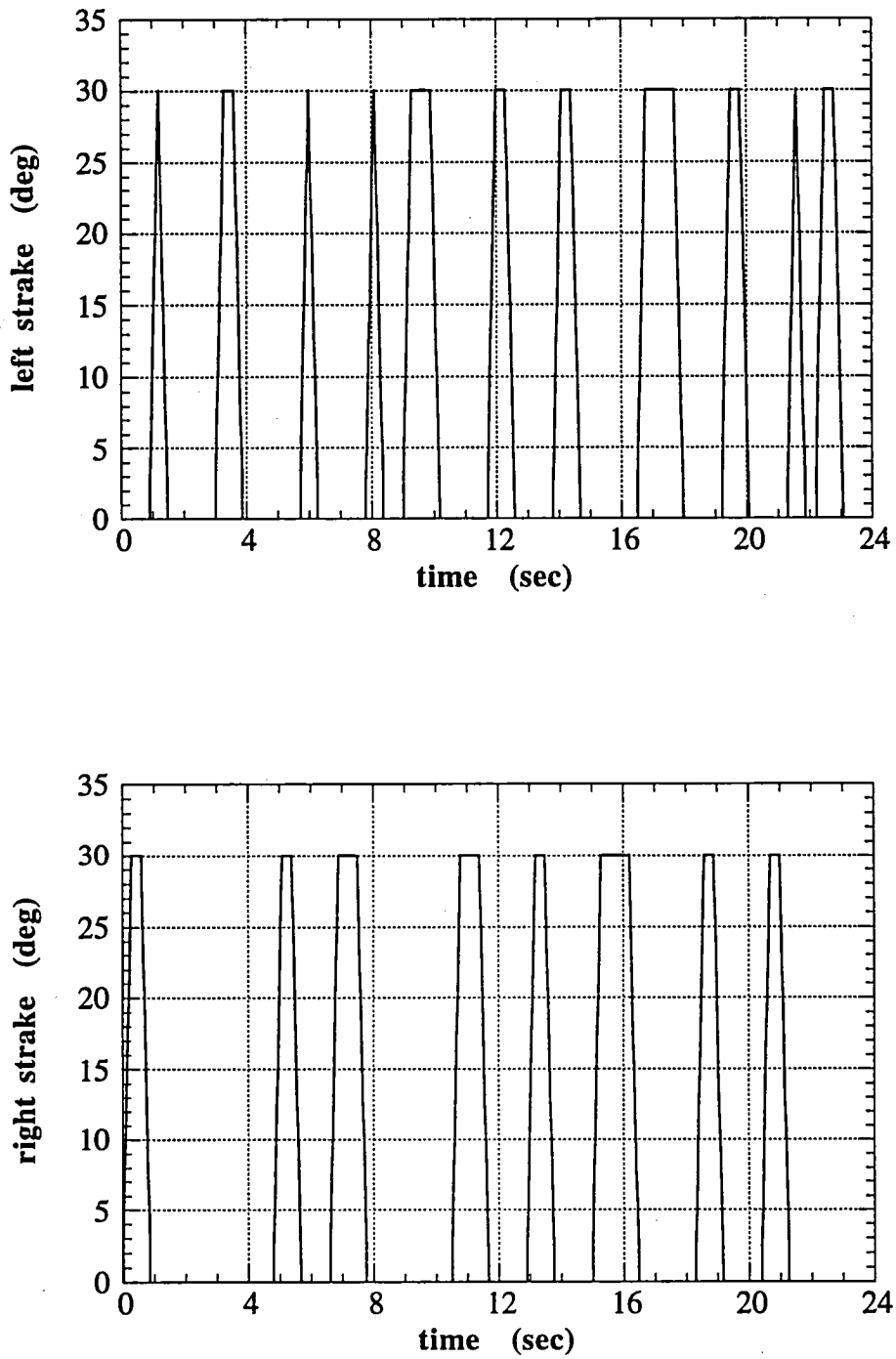


Figure 6 F-18 HARV Optimal Lateral Left/Right Strake Inputs, $\alpha = 40$ degrees

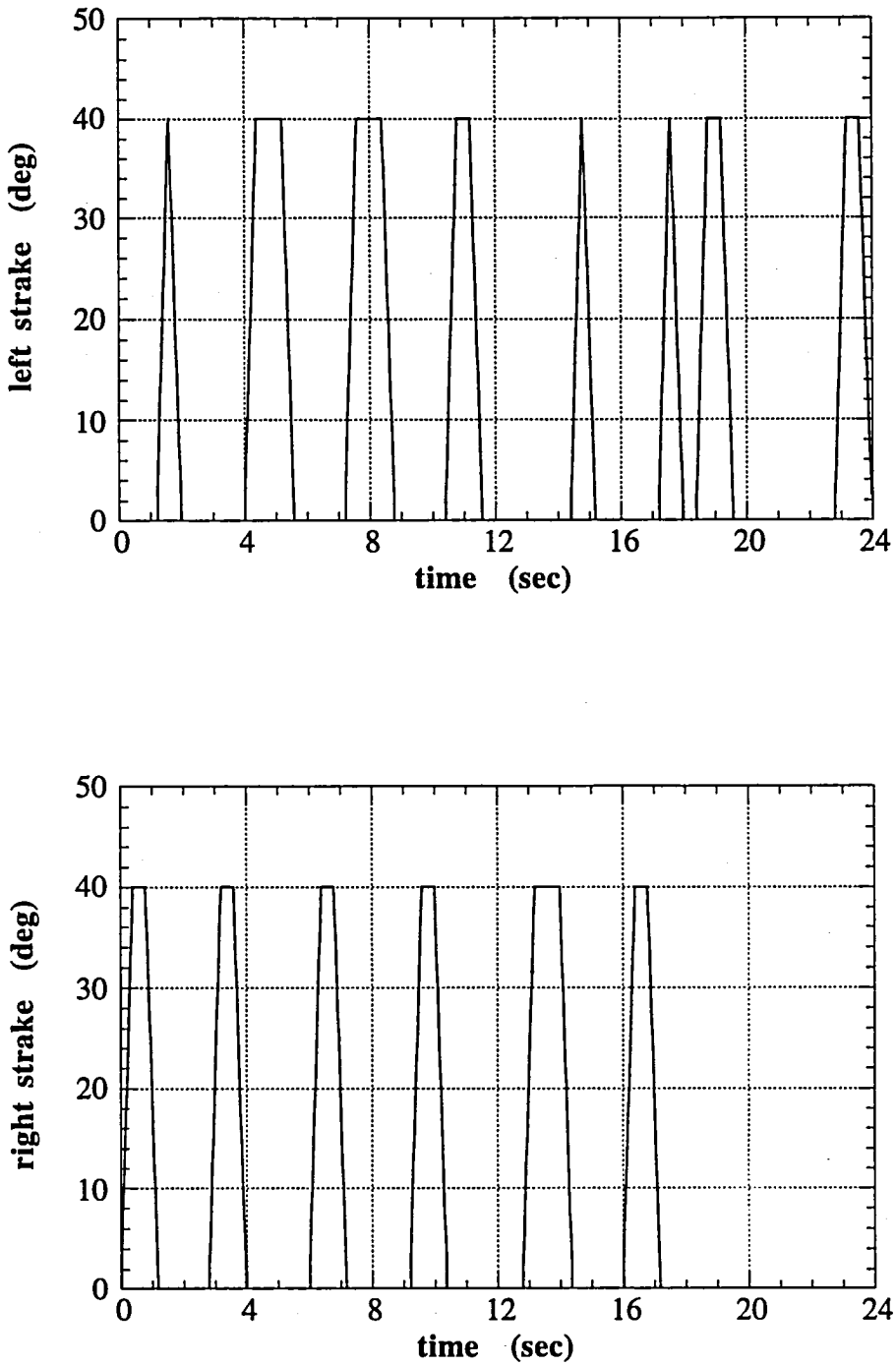
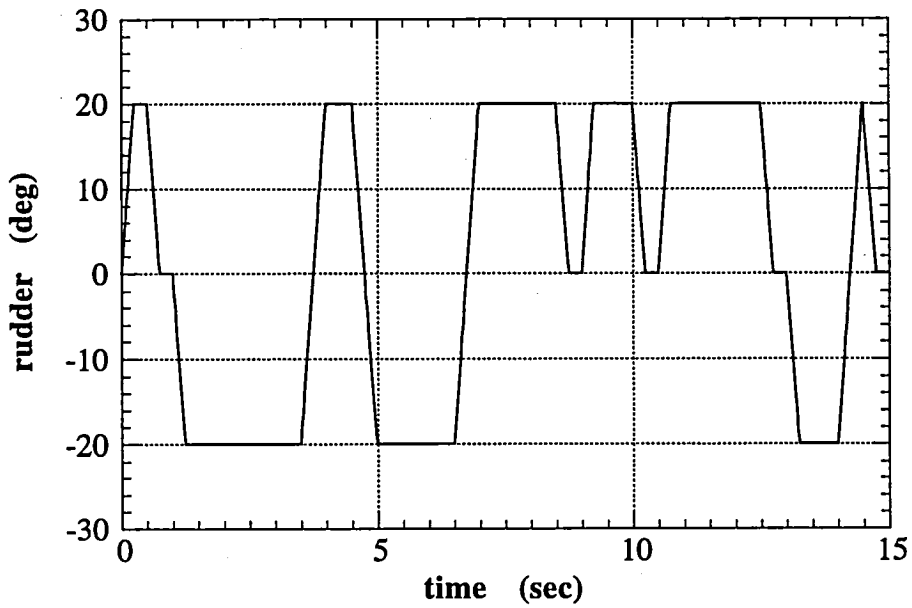


Figure 7 F-18 HARV Optimal Lateral Left/Right Strake Inputs, $\alpha = 50$ degrees



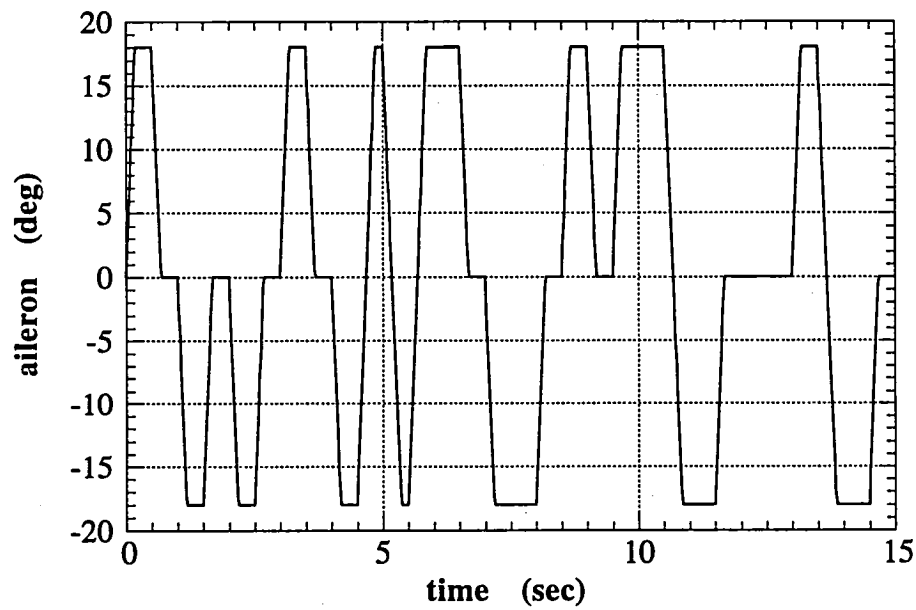
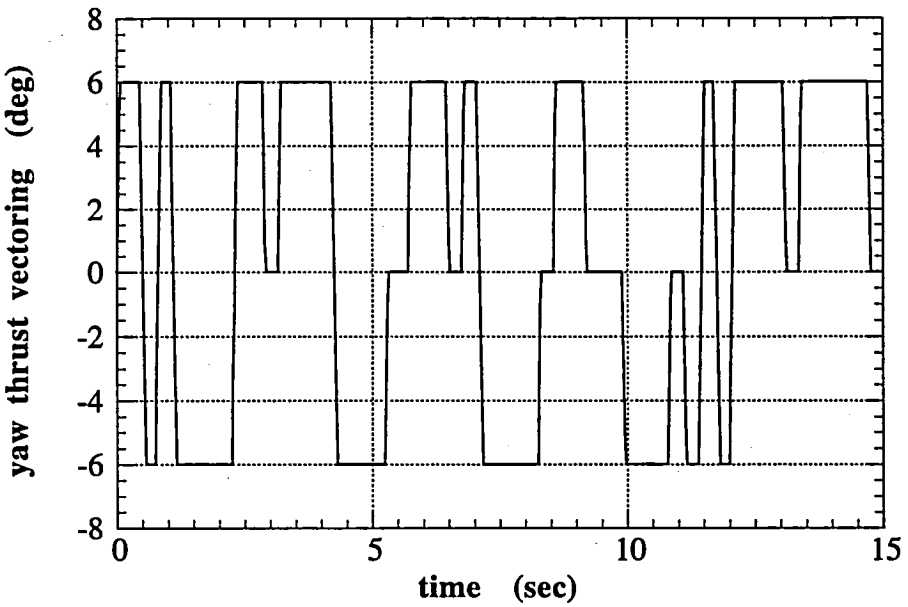


Figure 8 F-18 HARV Optimal Lateral Rudder/Aileron Inputs, $\alpha = 40$ degrees



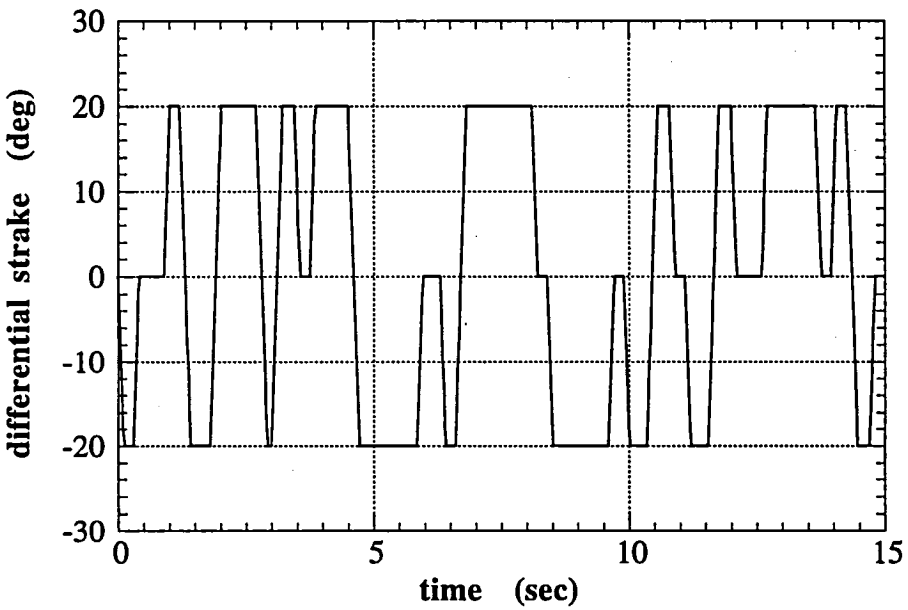


Figure 9 F-18 HARV Optimal Lateral Yaw TV/Differential Strake Inputs, $\alpha = 40$ degrees

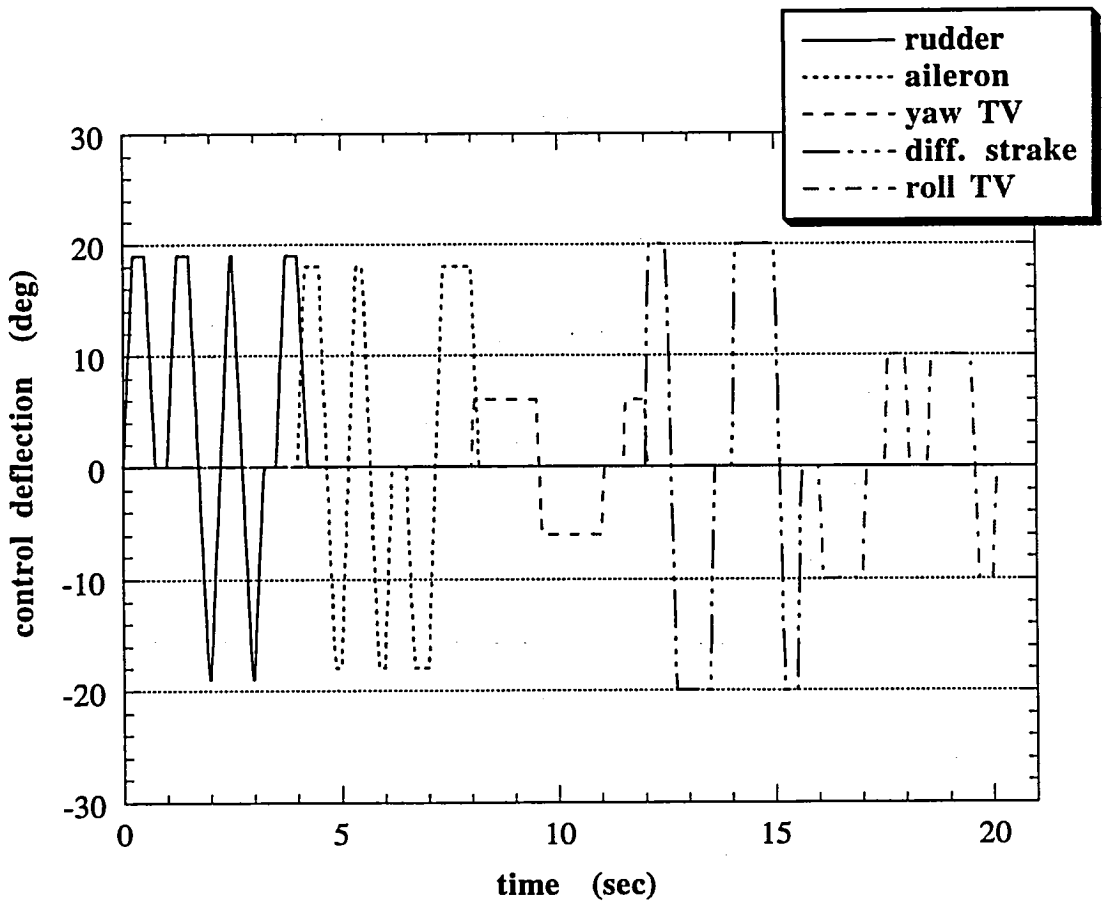
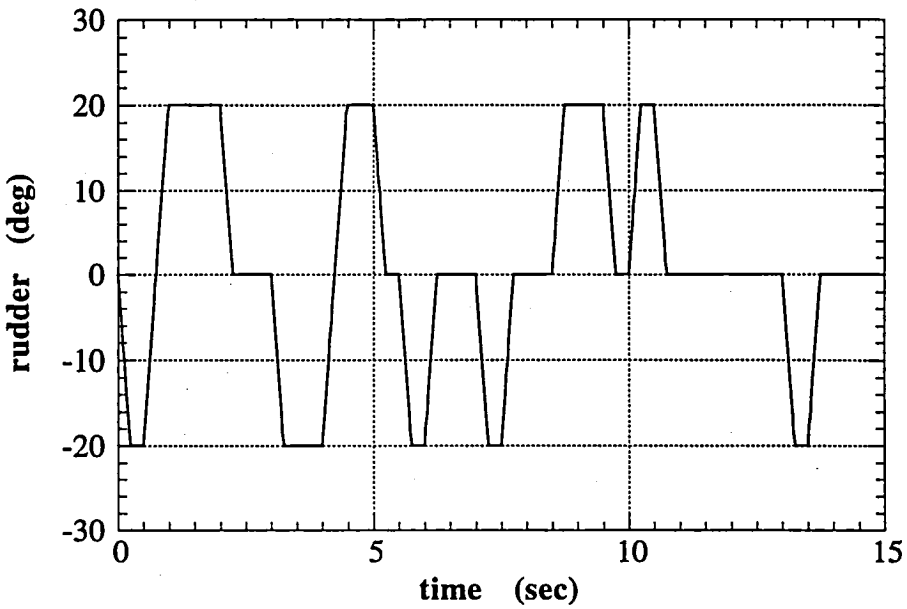


Figure 10 F-18 HARV Optimal Lateral Rudder/Aileron/Yaw TV/Differential Strake/Roll TV Inputs, $\alpha = 40$ degrees



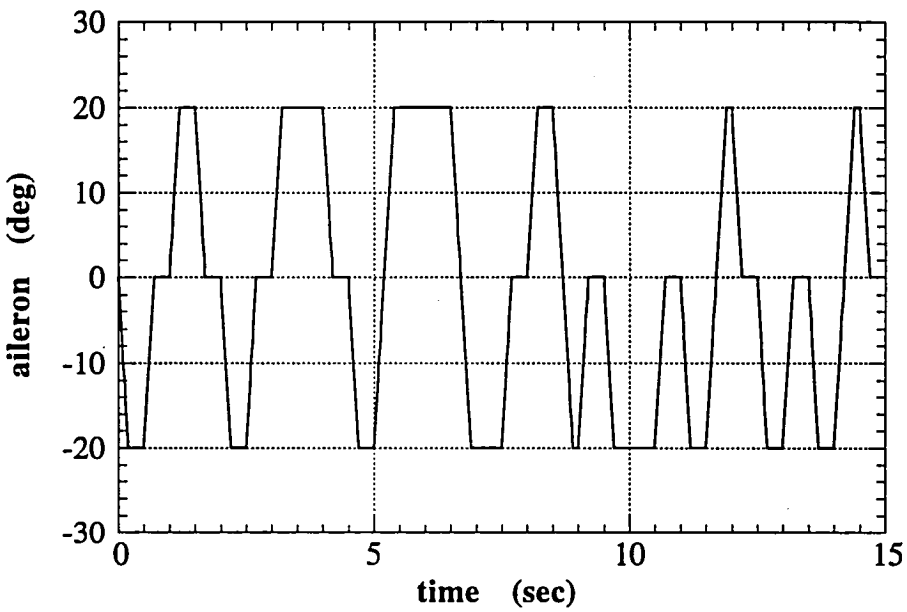
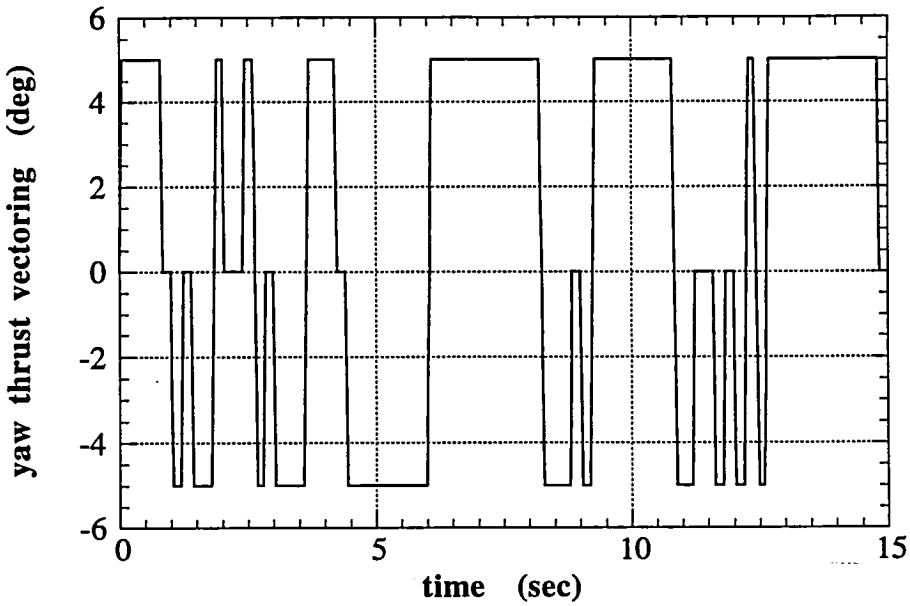


Figure 11 F-18 HARV Optimal Lateral Rudder/Aileron Inputs, $\alpha = 50$ degrees



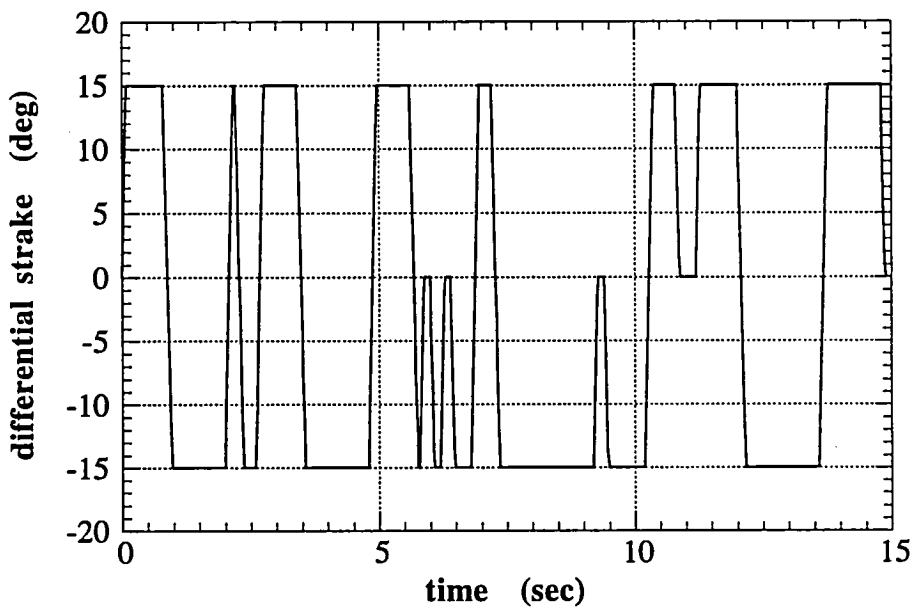


Figure 12 F-18 HARV Optimal Lateral Yaw TV/Differential Strake Inputs, $\alpha = 50$ degrees

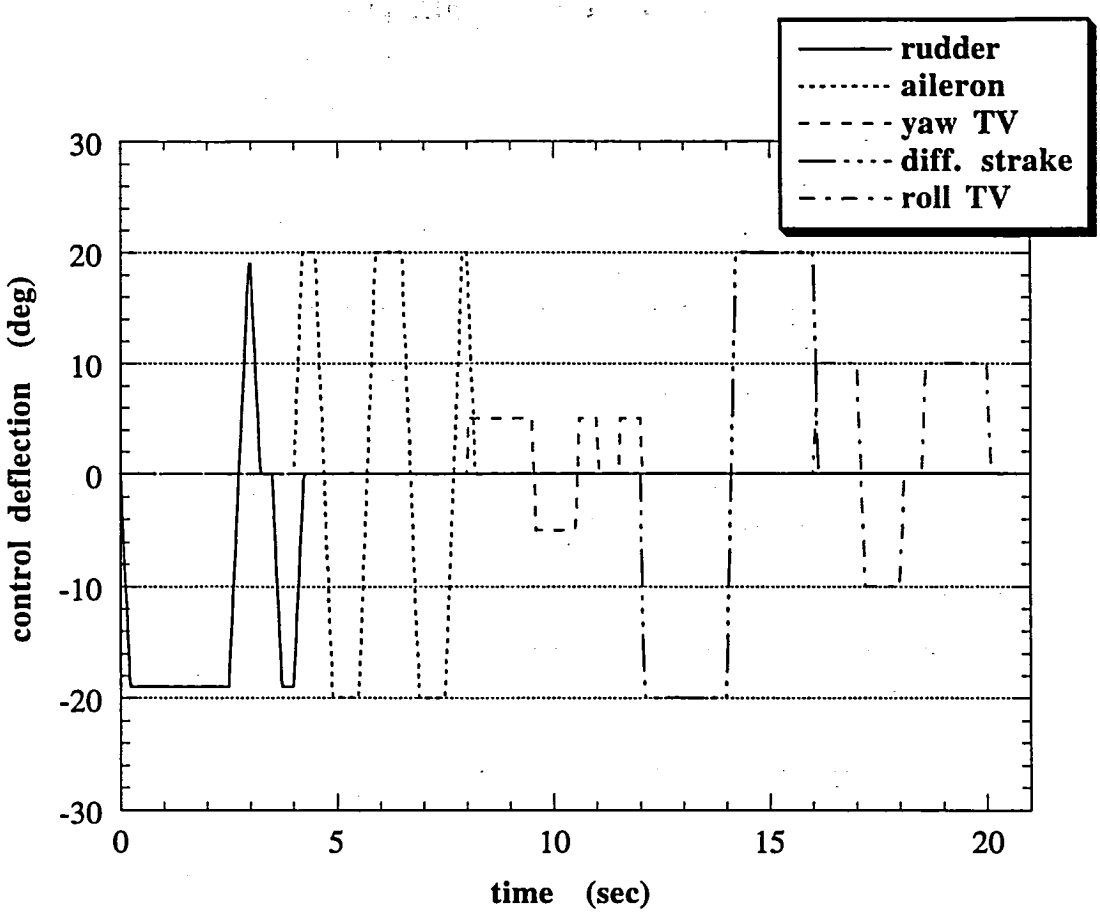


Figure 13 F-18 HARV Optimal Lateral Rudder/Aileron/Yaw TV/Differential Strake/Roll TV Inputs, $\alpha = 50$ degrees

REPORT DOCUMENTATION PAGE

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1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1995	Contractor Report

4. TITLE AND SUBTITLE
F-18 High Alpha Research Vehicle (HARV) Parameter Identification Flight Test Maneuvers for Optimal Input Design Validation and Lateral Control Effectiveness

5. FUNDING NUMBERS
C NAS1-19000

WU 505-64-52-01

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681-0001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
NASA CR-198248

11. SUPPLEMENTARY NOTES
Langley Technical Monitor: James G. Batterson

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified Unlimited

Subject Category - 05

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)
Flight test maneuvers are specified for the F-18 High Alpha Research Vehicle (HARV). The maneuvers were designed for open loop parameter identification purposes, specifically for optimal input design validation at 5 degrees angle of attack, identification of individual strake effectiveness at 40 and 50 degrees angle of attack, and study of lateral dynamics and lateral control effectiveness at 40 and 50 degrees angle of attack. Each maneuver is to be realized by applying square wave inputs to specific control effectors using the On-Board Excitation System (OBES). Maneuver descriptions and complete specifications of the time/amplitude points define each input are included, along with plots of the input time histories.

14. SUBJECT TERMS
Flight test maneuvers, parameter identification, optimal input design, strake effectiveness, lateral dynamics, lateral control effectiveness, and F-18 HARV

15. NUMBER OF PAGES
48

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		

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